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Optical Loss Analysis of Silicon Rich Nitride Waveguides

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Abstract *An analysis of the propagation loss in high-index LPCVD-grown silicon rich nitride (SRN) slab waveguides and channel waveguides is presented. A propagation loss as low as 0.6 dB/cm has been achieved.*

Introduction

For applications of optical waveguides, it is essential to minimize propagation loss. The low propagation loss is one of the reasons for the success of integrated optics based on doped silica [1]. Other advantages of this technology include polarization-independent operation and the fact that device fabrication relies on scalable technologies that have been developed in semiconductor industry. However, a significant drawback is the low integration density of components. This drawback is caused by the inevitably low index contrast between core and cladding of doped silica waveguides, which does not permit reduction of bending radii of waveguides below ~10 mm.

Alternative material systems have been proposed to overcome the mentioned drawback, while maintaining the positive features of the doped silica technology. An example is the silicon oxynitride (SiON) technology [2], which permits bending radii of ~1 mm.

A further increase in integration density is to be expected in the near future. In this context, the use of silicon rich nitride (SRN) as core waveguiding material opens up possibilities beyond the reach of silicon oxynitride.

This paper presents an analysis of the propagation loss in SRN slab waveguides and channel waveguides on the basis of different characterization methods.

Silicon rich nitride properties

Silicon rich nitride is deposited by low-pressure chemical vapor deposition (LPCVD), using $SiCl_2H_2$ and NH_3 as precursors. The material is characterized by a high refractive index and low mechanical stress.

The high refractive index of SRN, compared to silica, enables the realization of small bending radii. The index contrast of our waveguides (Δn=0.6) permits bending radii of ~40 µm without radiation losses [3]. A consequence of the high-index contrast is the fact that the cross-sectional dimensions of single-mode waveguides are submicron (~ 0.6 x 0.6 µm).

Low mechanical stress is important to omit material birefringence and to facilitate device fabrication. Ultralow stress values (<10 MPa) have been reported [4]. This is significantly less than the very high stress value (1.2 GPa [5]) of stoichiometric silicon nitride (Si_3N_4), which grounds the interest in SRN for optical waveguide applications. The mechanical stress in our layers is below 100 MPa.

Details on our fabrication process have been published elsewhere [6].

FTIR analysis

Material layers that are deposited using precursors that incorporate both hydrogen and nitrogen may contain significant amounts of N-H bonds. This is the case for both plasma-enhanced and low-pressure chemical vapor deposition [7]. N-H bonds have their intrinsic infrared absorption at a wavenumber of 3350 cm^{-1}. The first overtone of this frequency is found at a wavelength of 1510 nm. The tail of this peak leads to absorption losses in the wavelength region of interest. Annealing of the layers at high temperatures can be used to largely remove the N-H bonds [7, 8].

Fourier transform infrared spectroscopy (FTIR) was applied to investigate whether our as-deposited SRN layers incorporate N-H bonds and to see what the influence of annealing is. An FTIR spectrum of an as-deposited SRN layer is shown in figure 1.

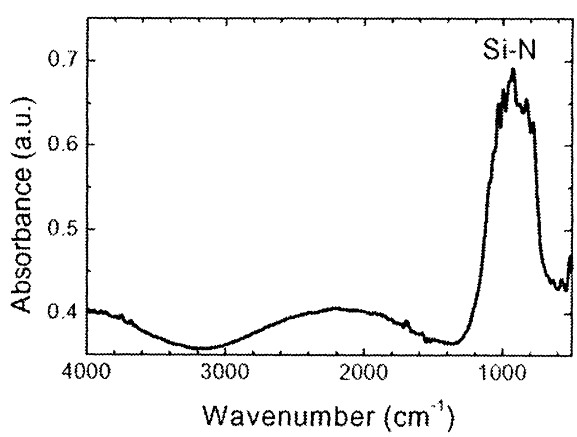

Figure 1: FTIR spectrum of a 1.2-µm-thick as-deposited SRN layer. Note that there is no N-H related absorption at 3350 cm^{-1}. The sinusoidal shape is due to etalon effects in the measurement setup.

The FTIR analysis shows that the amount of N-H bonds in our as-deposited SRN layers is lower than the detection limit of FTIR. This observation is in agreement with published results [4].

Dual prism coupling analysis

Optical loss spectra around the wavelength region of interest of slab SRN waveguides have been measured using dual prism coupling [9]. This characterization method provides detailed information about N-H related absorption and gives an absolute number for the propagation loss in slab waveguides. This information is useful since losses due to sidewall roughness are excluded, which helps to identify loss mechanisms.

1.2-μm-thick SRN layers deposited onto thermally oxidized silicon wafers were used for this analysis. 2-μm-thick as-deposited PECVD-grown SiON layers with a refractive index of 1.52 on similar wafers were used as a reference.

Figure 2 shows a wavelength spectrum of the propagation loss of both an as-deposited SRN layer and an as-deposited SiON layer. The vertical scale is obtained by varying the prism separation [9].

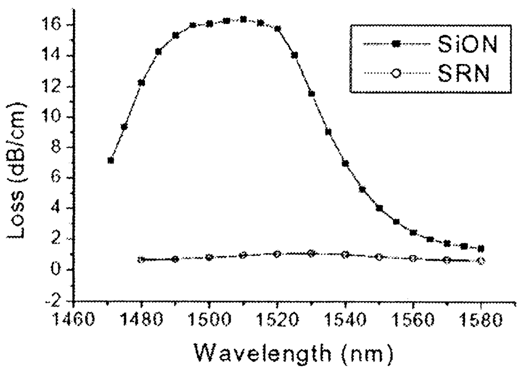

Figure 2: Propagation loss spectrum of an as-deposited SRN slab waveguide and an as-deposited SiON slab waveguide.

Figure 2 confirms that the N-H related absorption in SRN is negligible compared to as-deposited PECVD-grown SiON. The propagation loss in SRN is shown on an expanded scale in figure 3. A small absorption peak can be seen. The height of the peak decreases by annealing at 1100 °C, although it doesn't disappear completely.

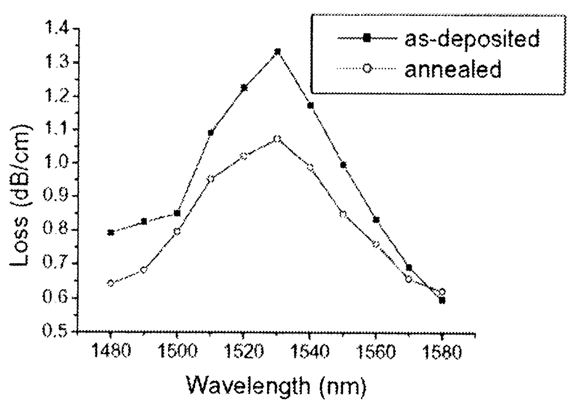

Figure 3: Propagation loss spectrum of an as-deposited SRN slab waveguide and an SRN slab waveguide that has been annealed at 1100 °C.

The propagation loss at a wavelength of 1580 nm is 0.60 ± 0.05 dB/cm.

Propagation loss in channel waveguides

The cutback method was used to determine the propagation loss in multi-mode SRN channel waveguides (1.3 x 8 μm) [6]. The obtained value is 0.7 ± 0.3 dB/cm. The fact that this value is close to the propagation loss in slab waveguides can be understood by the fact that sidewall roughness doesn't play an important role for multi-mode waveguides of these dimensions.

We expect to be able to determine the propagation loss in single-mode waveguides in the near future.

Conclusions

The analysis of the propagation loss in SRN slab waveguides points out that as-deposited SRN exhibits a small degree of N-H related absorption, which can be reduced by annealing at 1100 °C.

We achieved a propagation loss in high-index SRN slab waveguides as low as 0.60 ± 0.05 dB/cm at a wavelength of 1580 nm, which is a value that is in agreement with loss measurements of multi-mode waveguides. It leads us to conclude that SRN is a promising candidate for applications in high-density integrated optics

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